ST012 Remedial Action
Field Variance Memorandum 6 – Pilot Study Supplemental Data and Evaluation Metrics

Date: 14 November 2018

From: Amec Foster Wheeler Environment & Infrastructure, Inc.

To: Catherine Jerrard (AFCEC)

Subject: **Supplemental Data and Evaluation Metrics**
Pilot Study Implementation Work Plan
Former Liquid Fuels Storage Area (ST012)
Former Williams Air Force Base – Mesa, Arizona

1.0 INTRODUCTION

This Field Variance Memorandum (Memo) is a variance to the Final Pilot Study Implementation Work Plan (Amec Foster Wheeler, 2018) to address Arizona Department of Environmental Quality (ADEQ) requests for supplemental data and evaluation metrics for the Pilot Study at the Former Liquid Fuels Storage Area (ST012) at the former Williams Air Force Base (ADEQ, 2018).

A response to the ADEQ comments was prepared and is included as Attachment 1. Only those responses that include a change or addition to the Work Plan are further discussed in this memo.

2.0 MODIFICATIONS TO THE WORK PLAN TEXT

The use of acronyms and abbreviations in the Work Plan was reviewed. A revised Abbreviations and Acronyms list is provided as Attachment 2.

Text in Subsection 4.2.3 concerning testing related to micronutrients has been modified. A revised page for this subsection is included as Attachment 3.

Introduction text in Section 6 has been updated to clarify section is provided as a general description of future transition activities that are not a component of the pilot study. Revised page is included as Attachment 4.

Attachment J, decision matrix and criteria for enhanced bioremediation has been updated to include evaluations of phosphorus, methane, and PIANO data. Revised table is included as Attachment 5.

3.0 ADDITIONS TO MONITORING

The geochemical analysis performed for all of the outlined compounds will support assessment of the presence of the sulfate-reducing bacteria.

- As an extension of the re-baseline sampling event, a minimum of three wells with high iron (>20 mg/L) during the Pilot Study re-baseline and a minimum of three with low total iron (<10 mg/L) will be analyzed using field test kits for ferrous and total iron.
- BioTrap samplers included in the Work Plan for qPCR analysis will also be analyzed for petroleum degraders using Microbial Insights QuantArray Petroleum analysis.

Updated rows for Table 5-1 are included as Attachment 6 that show these analysis additions.

4.0 REFERENCES

Arizona Department of Environmental Quality, 2018. *Request for Supplemental Data and Evaluation Metrics, Williams Air Force Base, Mesa, Arizona*. E-mail correspondence dated June 19, 2018.

Amec Foster Wheeler Environment & Infrastructure Inc., 2018. *Pilot Study Implementation Work Plan for Operable Unit 2 Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona*. Prepared for the Air Force Civil Engineer Center. Final Report dated 5 April 2018. Contract No. FA8903-09-D-8572-0002

ATTACHMENT 1 RESPONSE TO ADEQ COMMENTS

Response to 19 June 2018 ADEQ Request for Supplemental Data and Evaluation Metrics
ST012 Pilot Study Implementation
Former Williams Air Force Base
Mesa, Arizona

1. Provide a complete acronym list [example= "RAO"].

Response: A revised acronym list is provided with Field Variance Memorandum (FVM) 6.

2. The Pilot Study Implementation Work Plan (April 2018) baseline and subsequent geochemistry analyses should include:
   - Temperature
   - pH
   - ORP
   - DO
   - Ferrous Iron
   - Total Iron
   - Phosphorous
   - Hydrogen Sulfide
   - Methane
   - Alkalinity
   - Arsenic

(a) Please add Phosphorous, Methane, and Ferrous Iron to the analyses.
(b) Please ensure that the Section 4.2.3-referenced analyses are added to both Table 5-1 and to the Decision Matrix (Appendix J).

> If sulfate-reducing bacteria (SRB) populations are to be "inferred" by indirect evidence, then baseline and geochemical parameter that might support "inferred" evidence lines (like the list above) should be collected before EBR and during EBR to support the presumption that SRB are present and active.

Response: Temperature, pH, ORP, and DO are part of field parameters normally collected with samples except for hot wells where damage to the instruments could occur and are included in the work plan. Total iron and arsenic are also included in the work plan. Phosphorus and methane will be added for future quarterly monitoring events and are incorporated into the decision matrix. Ferrous iron hold times for laboratory analysis are short, and even if met iron oxidation/reduction is possible prior to analysis. Therefore, a field test kit will be used to evaluate ferrous iron relative to total iron. Continued use of the field kit will only be included if a reliable relationship is not demonstrated.

The second paragraph of Section 4.2.3 has been modified as follows:

"Field analyses of ground water samples will include geochemical parameters (sulfate, temperature, dissolved oxygen, pH, redox potential, and specific *conductance).* Laboratory analyses will include geochemical parameters: sulfate, nitrate, arsenic, manganese, iron, and alkalinity (total, as calcium carbonate, bicarbonate as calcium carbonate, and carbonate as calcium carbonate). These parameters *were* sampled *as part of the baseline event* and *may be resampled* during EBR *if degradation by SRB appears to be limited* to assess if the availability of any of these elements or compounds are potentially limiting respiration. Other parameters may be included during EBR as necessary to investigate areas of diminished sulfate-reducing activity: chloride, sulfide, ortho- and total phosphorus, carbon dioxide, methane, and total organic carbon. Depending on the comparison of baseline results to results during EBR testing, additional amendments may be added to maintain robust degradation."

3. The Pilot Study Implementation Work Plan (April 2018) should include baseline studies:
(a) Targeting benzene-degrading microbes.
(b) Measuring stable (baseline population) microbe colonies (new BioTrap® sampler structures will show opportunistic "growth" populations as microbes move onto and multiply on a "newly" installed BioTrap® sampler).
(c) Measuring the sulfate nutrient impact on microbe colony populations after "Time Zero" population data is acquired.

> The above items assist in providing information. The April 2018 *Pilot Study Implementation Work Plan* (as interpreted) does not appear to confirm that benzene degraders exist, does not provide "Time Zero" population data, does not provide nutrient confirmation, and does not provide enhanced microbe populations after nutrient injections. The BioTrap® sampler use, quantitative polymerase chain reaction (qPCR) assessments, and Total Eubacteria (EBAC) testing for only sulfate reducing bacteria and total microbial population sizes will not confirm that indigenous benzene biodegraders are present. The April 2018 *Pilot Study Implementation Work Plan* (as interpreted) will also not confirm that any present benzene degraders are also sulfate-reducers. Benzene degradation and sulfate reduction are independent activities.

Response: Re-analysis of the BioTrap samplers collected during the re-baseline sampling event for benzene degraders was added. Bio Trap samples for baseline population is already included in the Pilot Study Work Plan and was completed.

4. The Pilot Study Implementation Work Plan (April 2018) should include baseline quantitative polymerase chain reaction (qPCR) assessments using a one-time, discrete interval groundwater sample from each targeted groundwater monitoring well.

Response: Baseline qPCR assessment using BioTraps has been provided including two wells in each zone. As previously discussed in BCT conference calls, sampling of each monitoring well is not necessary.

5. Obtain baseline data if Stable Isotope Probe (SIP) assessments are to be conducted. Assessments at proposed 3-12 months post-injection may not be helpful to assess contaminant biodegradation with no corresponding baseline data.

Response: The primary purpose of SIP will be to demonstrate that site contaminants are being degraded by bacteria under enhanced conditions. As previously indicated, baseline SIP data is not necessary for this demonstration.

6. Provide expected, specific data trends which will demonstrate progress toward Remedial Action Objectives (RAOs).

Response: The decision matrix identifies benzene trends and estimated half lives as the primary measurement of trends that will support acceptable progress.

7. Provide the expected decision points and supporting data required to commit to full-scale implementation.

Response: See previous response. Benzene trends that support the remedial objectives will be the primary evaluation criteria to evaluate during the pilot test. The pilot test will be conducted in phases and address the entire site.

8. Detail how collected pilot test data will be incorporated into remediation models.

Response: The remediation model is based on the inputs described in the RD/RA work plan. Updates to the flow model have been incorporated as described in the Pilot Study Implementation Work Plan. Pilot study data will be used to reevaluate flow, contaminant distribution, and bioreaction parameters included in the previous model. Where appropriate, these parameters will be updated.

9. Demonstrate that the existing monitoring well network will provide statistically valid data sets for evaluating EBR progress.

Response: Additional characterization data collected over the past two years demonstrate that the existing well network is adequate to evaluate changes at the site during pilot study implementation. A statistical evaluation is not necessary.

10. Revise Section 6.1 Requirements for EBR System Shutdown (Pilot Study Implementation Work Plan (April 2018)) to include updated transition criteria. Section 4.3.3 Transition to Monitoring (Remedial Design and Remedial Action Work Plan, (May 2014)) is no longer a valid reference. Include Appendix F and Appendix J updates (Pilot Study Implementation Work Plan (April 2018)).

Response: The pilot study will consist of the initial injection phase divided over four periods as described in the work plan. It is anticipated that if the pilot study is successful, additional EBR injection phases after the pilot study implementation will likely be required. Because the work plan was redefined as a pilot study implementation, section 6 provides guidelines to future transitions and is not specific to the end of the pilot study. The requirements for updated transition criteria will be documented in future reporting. To clarify this, the intro paragraph to Section 6 is modified as follows:

"This section discusses how the decision to transition from active EBR to monitoring *would generally* be made and describes the *general* decommissioning process for the active EBR system. *However, following implementation of the pilot study activities, the transition criteria section will be reviewed and updated, assuming that remedy implementation will continue as outlined in the RD/RAWP*."

11. Include a contingency plan outline to move to different terminal electron acceptors. Information was provided that some areas without depleted sulfate exist, which is interpreted as potential areas not under the influence of sulfate reduction.

Response: The decision matrix provides the general evaluation process that would lead to a decision to move to a different electron acceptor. If such a decision is made, a detailed plan will be developed at that time and will incorporate results obtained from the pilot study.

12. Include an outline for an aerobic bioremediation contingency plan. Prior comment responses have indicated the use of aerobic methods cannot be totally ruled out for future remediation in specific areas. However, the reviewers note that aerobic degraders may not survive after high sulfate concentration injections to stimulate sulfate-reduction.

Response: Aerobic bioremediation would be a change to a different electron acceptor, oxygen. See response to the previous comment.

13. Include detailed plans and timelines to perform additional characterization and address contaminant plume areas unaffected by EBR. The post-SEE (steam enhanced extraction) soil boring and well installation results indicated areas likely requiring characterization and groundwater monitoring.

Response: 13. Additional characterization of some areas may be needed; however, as previously indicated, the AF does not believe that characterization of these potential areas is necessary prior to implementation of the pilot study. In addition, data collected during the pilot study will likely lead to refinement of areas where additional characterization may be beneficial. The requested plans for additional characterization, if necessary, will be developed as site data is collected, but will be separate from implementation of the pilot study.

14. Provide soil boring, groundwater well installation and sampling plans to confirm tracer transport model.

Response: Additional soil borings, wells, and sampling are not needed to confirm the model. Travel time will be assessed using monitoring data for sulfate in existing wells as outlined in the work plan. Some variation from the model is expected since the model outputs in Appendix F of the Pilot Study Implementation Work Plan are based on non-reactive transport.

ATTACHMENT 2 LIST OF ACRONYMS AND ABBREVIATIONS

LIST OF ACRONYMS AND ABBREVIATIONS

%	percent
µg/L	micrograms per liter
3D	three-dimensional
ADEQ	Arizona Department of Environmental Quality
AMEC	AMEC Environment & Infrastructure, Inc. (now known as Amec Foster Wheeler Environment & Infrastructure, Inc.)
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
BCT	Base Realignment and Closure (BRAC) Cleanup Team
bgs	below ground surface
BTEX+N	benzene, toluene, ethylbenzene, total xylenes, and naphthalene
BTOC	below top of casing
COC(s)	contaminant(s) of concern
COPC(s)	contaminant(s) of potential concern
CZ	cobble zone
DIC	dissolved inorganic carbon
DNA	deoxyribonucleic acid
DO	Dissolved Oxygen
DRO	diesel range organics
EBAC	total eubacteria
EBR	enhanced bioremediation
EPA	U.S. Environmental Protection Agency
FVM	Field Variance Memorandum
ft	feet, foot
g/L	grams per liter
GAC	granular activated carbon
gpm	gallons per minute
GRO	gasoline range organics
HASP	Health and Safety Plan
HDPE	high density polyethylene
ICP	inductively coupled plasma
JP-4	jet propulsion fuel grade 4
lb(s)	pound(s)
LNAPL	light non-aqueous phase liquid
LPZ	Low Permeability Zone
LSZ	Lower Saturated Zone
MCL	maximum contaminant level
MCP	main control panel
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
MPE	multi-phase extraction
NA	not available
NAPL	non-aqueous phase liquid

LIST OF ACRONYMS AND ABBREVIATIONS (CONT.)

OU	Operable Unit
OWS	oil-water separator
ORP	Oxidation Reduction Potential
PDI	Pre-Design Investigation
PIANO	paraffins, isoparaffins, aromatics, naphthalenes, and olefins
PID	photoionization detector
PLFA	phospholipid fatty acid
PPM	parts per million
PVC	polyvinyl chloride
QAPP/SAP	Quality Assurance Project Plan/Sampling and Analysis Plan
qPCR	quantified polymerase chain reaction
RA	Remedial Action
RAO	Remedial Action Objectives
RD/ RAWP	Remedial Design and Remedial Action Work Plan
RODA	Record of Decision Amendment
ROI	radius of influence
RT	reactive transport
SEE	steam enhanced extraction
SIP	stable isotope probing
SIW	steam injection wells
SOP	standard operating procedure
SRB	sulfate-reducing bacteria
SVE	soil vapor extraction
ST012	Site ST012, the former Liquid Fuels Storage Area
SVOC	semi-volatile organic compound
TEA	terminal electron acceptor
TDS	total dissolved solid
TIZ	Thermal Influence Zone
TMP	temperature monitoring point
TPH	total petroleum hydrocarbons
tpy	tons per year
TTZ	Thermal Treatment Zone
UWBZ	Upper Water Bearing Zone
VFD	variable frequency drive
VOC(s)	volatile organic compound(s)

ATTACHMENT 3 REVISED SUBSECTION 4.2.3 MICRONUTRIENT DOSING

A double diaphragm pump will deliver TEA to the direct pumping injection wells via HDPE piping installed at ST012. Direct pumping wells will be utilized in groups of five as indicated in Table 4-2. Flow rates are expected to average approximately 5 gpm, and will depend on the subsurface response to injection for actual flow rates. Using this injection flow rate an estimate for total injection time was developed and is presented in Table 4-2. Mass of injected TEA is also presented in Table 4-2. A minimum of one-half frac tank batch (or 12.1 tons of sodium sulfate) was applied over the four injection periods to aid in TEA distribution in the subsurface. The total injection period for Phase 1 is estimated at approximately 300 days including built-in delays between the four injection periods.

4.2.3 Micronutrient Dosing

Microorganisms not only require electron donors and TEAs to facilitate cell growth and maintain energy, but also need certain other trace elements at much lower concentrations. Micronutrients such as iron, nickel, cobalt, molybdenum, and zinc are typically abundant enough in aquifer minerals that no additional dosing is required. However, in some circumstances, biodegradation of COCs can stall due to a lack of micronutrients.

Field analyses of ground water samples will include geochemical parameters (sulfate, temperature, dissolved oxygen, pH, redox potential, and specific conductance). Laboratory analyses will include geochemical parameters: sulfate, nitrate, arsenic, manganese, iron, and alkalinity (total, as calcium carbonate, bicarbonate as calcium carbonate, and carbonate as calcium carbonate). These parameters were sampled as part of the baseline event and may be resampled during EBR if degradation by SRB appear to be limited to assess if the availability of any of these elements or compounds are potentially limiting respiration. Other parameters may be included during EBR as necessary to investigate areas of diminished sulfate-reducing activity: chloride, sulfide, ortho- and total phosphorus, carbon dioxide, methane, and total organic carbon. Depending on the comparison of baseline results to results during EBR testing, additional amendments may be added to maintain robust degradation.

Nutrient limitation will be assessed indirectly as diminished sulfate-reducing activity. Sulfate-reducing activity can be monitored through hydrocarbon concentrations (lack of contaminant reductions), sulfate concentrations (lack of sulfate utilization) and periodic quantified polymerase chain reaction (qPCR) monitoring (lack of population changes over time in response to sulfate presence). If evidence of nutrient limitation is observed, data will be evaluated to determine whether the cause is limitation of macro or micro-nutrients. Macro nutrients (e.g. nitrogen and phosphorous) will be measured directly. If analysis results reveal a single rate-limiting macro-nutrient then that single nutrient will be blended into the TEA stock solution in proportion to the observed concentration reduction.

If diminished sulfate-reducing activity is observed and the macro-nutrients are present, micro-nutrient limitation shall be assumed and a mix of micronutrients, Bionetix MICRO 14, or similar, may be added to TEA injection solutions and injected into the subsurface to increase biological activity. Biomatrix product MICRO 14 is a potential candidate for nutrient amendment if required. MICRO 14 is a proprietary blend of minerals, vitamins, and cellular building blocks that has been developed to support nutrient deficient groundwater at sites where enhanced

ATTACHMENT 4 REVISED SUBSECTION 6.1 REQUIREMENTS FOR EBR SYSTEM SHUTDOWN AND DECOMMISSIONING

6.0 EBR SYSTEM SHUTDOWN AND DECOMMISSIONING

This section discusses how the decision to transition from active EBR to monitoring would generally be made and describes the general decommissioning process for the active EBR system. However, following implementation of the pilot study activities, the transition criteria section will be reviewed and updated, assuming that remedy implementation will continue as outlined in the RD/RAWP.

6.1 Requirements for EBR System Shutdown

EBR will be implemented to achieve conditions (residual COC/ [COPC groundwater concentrations) at ST012 such that contaminants will degrade by natural attenuation to achieve the cleanup levels within the projected remedial timeframe (within 20 years of RODA 2 signature) after completion of EBR. The EBR system is designed with the anticipation that a steady state flux of sulfate into the treatment zone from upgradient of the site will continue so that ongoing biodegradation will satisfy the final remedial goal for ST012. Additional phases of EBR will likely be necessary to target residual areas of contamination. A further discussion of the transition from EBR to monitoring is discussed in the RD/RAWP (Section 4.3.3 and Appendix F). It is anticipated that the transition to monitoring will be supported by updates to the groundwater model using data from EBR for contaminant and sulfate concentrations to show projected conditions in the future consistent with the RA objectives and Cleanup Levels. The groundwater model will be updated based on data collected during active EBR and the evaluation will include sensitivity analysis of input parameters to evaluate uncertainty. The Decision Matrix in Appendix J also shows the decision points for this transition and identifies the primary criteria that will be evaluated in making the decision.

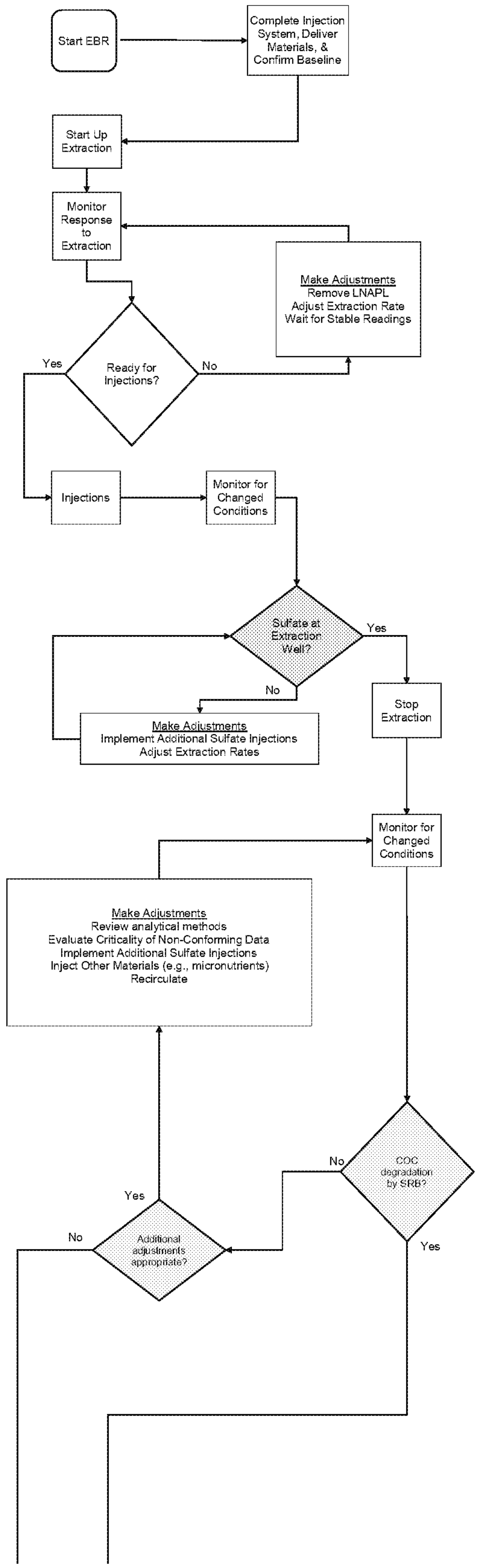
6.2 Selective Decommissioning of EBR System

Once subsurface conditions have met remedial goals for transition to monitoring, the EBR system will transition to a standby mode while monitoring continues at ST012. When the Air Force and the Regulatory Agencies agree that the EBR system will not be required, it will be decommissioned and dismantled. Downhole pump components and associated electrical and controls components will be removed from extraction wells, wellheads will be removed and wells prepared for use as monitoring locations until a time when they may be abandoned.

Process equipment will be disconnected and decontaminated as required, working from process inlet to treatment effluent to continue processing fluids in the system. Once the system can no longer process any contaminated fluids, fluids will be containerized and characterized for off-site disposal. All non-hazardous process equipment and materials will be either removed from the site for reuse or loaded into dumpsters for off-site disposal or recycling. Rental equipment and temporary facilities will be returned to vendors as appropriate.

ATTACHEMENT 5 UPDATED ST012 DECISION MATRIX AND CRITERIA FOR ENHANCED BIOREMEDIATION

ST012 Decision Matrix and Criteria for Enhanced Bioremediation
Former Williams Air Force Base
Mesa, Arizona



Decision Objective: To establish location is ready for EBR injections

Time Frame: 1 week-2 months

Criteria: Target Numerical Conditions

Parameter	Desired Trend	Method	Ideal	Non-Inhibiting	Units	Discussion
LNAPL	LNAPL recovery not sustained under pumping	field instrument	<1	<5	ft/week	LNAPL removal to be emphasized over EBR where significant migration to extraction wells occurs.
Water Levels	Hydraulic response consistent with expectation	field instrument				Differences may affect expected distribution
Extraction	Extraction rate and drawdown consistent with expectation	field instrument				Differences may affect travel times
Temperature	Stable or slowly changing	field instrument	<1		°F/day	Rapid temperature changes may lead to instability and population changes

Notes:
Parameters will be evaluated in different areas of the site and may not be demonstrated everywhere simultaneously. Expansion of ideal conditions to all desired treatment areas will be part of the optimization step

	Condition	Potential Adjustments
Potential Adjustments	1. LNAPL recovery does not meet criteria	a. Continue LNAPL removals, consider increased removal frequency b. Increase extraction drawdown to increase recovery rate. Once recovery diminishes return to design drawdown and retest recovery rate.
	2. Water levels, extraction flow rate, or drawdown inconsistent with expectation	a. Evaluate data. Adjust extraction set points and remeasure or adjust expected sulfate travel times b. Evaluate data. Consider injection adjustments if flow directions are different than expected
	3. Temperatures are changing rapidly at extraction or injection location	a. Continue to monitor and wait for stabilization

Decision Objective: To establish when pumping at individual extraction locations should be terminated

Time Frame: weeks-1 year after injections (note temporary shut downs planned at some wells to limit sulfate distribution until Phase 1 injections are complete)

Criteria: Target Numerical Conditions

Parameter	Desired Trend	Method	Target	Units	Discussion
Sulfate	Sulfate from injections arrives at extraction well	field kit	>50 above pre-injection	mg/L	Indicates arrival of injected sulfate

Notes:
Parameters will be evaluated in different areas of the site and decisions made for individual extraction wells.

	Condition	Potential Adjustments
Potential Adjustments:	1. Sulfate shows up earlier or later than expected	a. Consider in designing future injections. b. Adjust extraction/injection rates or future injection concentration.

Decision Objective: To Establish Biological Degradation by Sulfate Reducing Bacteria (SRB) at ST012 and has been Enhanced

Time Frame: 3-12 months post injection

Criteria: Target Numerical Conditions

Parameter	Desired Trend	Method	Ideal	Non-Inhibiting	Units	Discussion
VOCs	Decreasing	8260B				Decreasing VOCS in the presence of sulfate may indicate degradation
TPH (DRO/GRO)	Decreasing	8015B				Decreasing TPH in the presence of sulfate may indicate degradation
Iron	Increased in contaminated area relative to upgradient	6010C				If most of total iron is assumed to be Fe(II) in the subsurface (because of higher solubility), increasing iron indicates reduction of Fe(III) to Fe(II)
Manganese	Increased in contaminated area relative to upgradient	6010C				If most of total manganese is assumed to be Mn(II) in the subsurface (because of higher solubility), increasing Mn indicates reduction of Mn(IV) to Mn(II)
Phosphorous as orthophosphate	Stable	300.0				Decreasing concentration may warrant further evaluation for potential nutrient limitation
Nitrate	Depleted	9056A	<0.5	<1	mg/L	Depleted nitrate indicates degradation by nitrate reducing bacteria is active on site but likely not active at the monitored location
Sulfate	Increased	9056A	2,000-10,000*	30000*	mg/L	Sulfate concentrations in targeted range
Methane	Stable or decreased	RSK-175				Decreased concentration indicates sulfate utilization by microbes
PLFA (SIP)	^{13}C-enriched content in PLFA	Microbial Insights				Incorporation of ^{13}C in PLFA demonstrates bacteria have degraded ^{13}C-enriched seed contaminant into bacteria cells
DIC (SIP)	^{13}C-enriched content in DIC	Microbial Insights				Incorporation of ^{13}C in DIC demonstrates bacteria have degraded ^{13}C-enriched seed contaminant into dissolved inorganic carbon
SRB (qPCR)	Increased relative to baseline	Microbial Insights				Increased population indicates SRB response to sulfate amendment
EBAC (qPCR)	Increased relative to baseline	Microbial Insights				Increased population indicates total bacteria response to sulfate amendment
QuantArray-Petro (qPCR)	Increased relative to baseline	Microbial Insights				Increased population indicates benzene biodegradation by microbes
PIANO	BTEX+N component decreasing	Pace Analytical				BTEX+N decrease indicates biodegradation by microbes
Temperature	Stable or slowly changing	field instrument				Rapid temperature changes may lead to instability and population changes
pH	In Range	field instrument	7.5-8	5.5-9		Avoid pH range that would inhibit EBR
Eh	Reduced	field instrument	-220	<0	millivolts	(Correct to hydrogen electrode)Eh should be in expected range for anaerobic SRBs
DO	Depleted	field instrument	<0.5	<1.0	mg/L	Anaerobic activity will be inhibited if significant DO is present

Notes:
Parameters will be evaluated in different areas of the site and different zones (CZ, UWBZ, LSZ) and may not be demonstrated everywhere. Expansion of conditions to all desired treatment areas will be part of the optimization step
*Preliminary ranges for target sulfate concentrations in the formation. Values are subject to modification based on observation of SRB responses in the field to sulfate. Higher concentration may be present in the immediate vicinity of injection wells.

	Condition	Action
Potential Adjustments:	1. Most desired trends are met, but a few are not	a. Verify data quality, potentially test by alternate analytical methods b. Evaluate if non-conforming data represents a critical uncertainty for SRB enhancement or other data supersedes
	2. If several parameters are not met in all areas of the site	a. Implement additional injections to bring parameters into range and retest. b. Inject in different locations or recirculate to redistributed sulfate
	3. If geochemical parameters are in desired range but there is no sign of VOC/TPH degradation and no enrichment of ^{13}C in the PLFA or DIC	a. Evaluate other factors that could be limited EBR (e.g., lack of micronutrients) and implement additional extraction/injections if necessary b. Implement additional injections if necessary (e.g., to address micronutrients)
	4. If degradation by SRB can not be demonstrated after other measures, consider alternate technologies	a. Evaluate other technologies (e.g., pump and treat, chemical oxidation)

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ST012 Decision Matrix and Criteria for Enhanced Bioremediation
Former Williams Air Force Base
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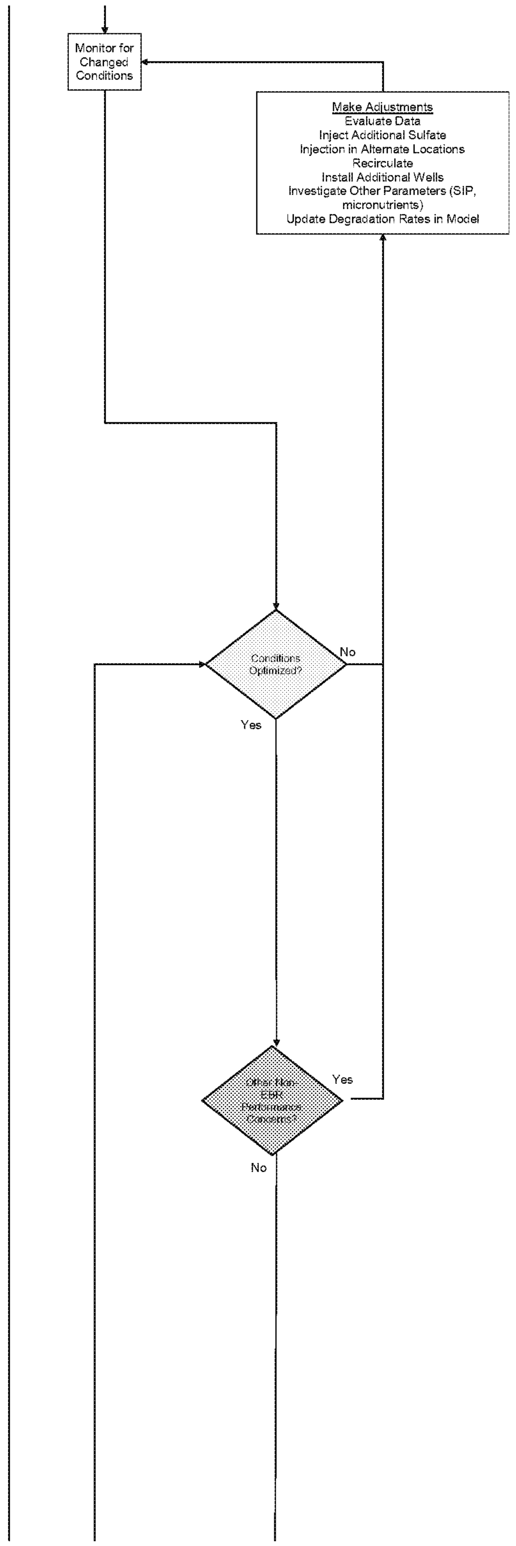

Decision Objective: Target Criteria to Optimize Biological Degradation by SRB at ST012

Time Frame: 6-36 months post initial injection

Criteria:

Parameter	Desired Trend	Method	Target Numerical Conditions: Average	Maximum	Units	Discussion
Benzene in CZ	Decreasing toward post EBR model targets	8260B	21*	27*	µg/L	Plot benzene trends by well and average for the zone over time and project timeframe to reach goal
Benzene in UWBZ	Decreasing toward post EBR model targets	8260B	210*	1400*	µg/L	Plot benzene trends by well and average for the zone over time and project timeframe to reach goal
Benzene in LSZ	Decreasing toward post EBR model targets	8260B	31*	270*	µg/L	Plot benzene trends by well and average for the zone over time and project timeframe to reach goal
TPH (DRO/GRO)	Decreasing	8015B				Decreasing TPH is an indicator of decreasing TPH flux from NAPL
Iron	Increased in contaminated area relative to upgradient	6010C				If most of total iron is assumed to be Fe(II) in the subsurface (because of higher solubility), increasing iron indicates reduction of Fe(III) to Fe(II)
Manganese	Increased in contaminated area relative to upgradient	6010C				If most of total manganese is assumed to be Mn(II) in the subsurface (because of higher solubility), increasing Mn indicates reduction of Mn(IV) to Mn(II)
Phosphorous as orthophosphate	Stable	300.0				Constant concentration ensures nutrient availability
Nitrate	Depleted	9056A	<0.5		mg/L	Depleted nitrate indicates degradation by nitrate reducing bacteria is active on site but likely not active at the monitored location
Sulfate	Sustained in target range	9056A	2,000-10,000**	30000**	mg/L	Sulfate concentrations in targeted range
Methane	Stable or decreased	RSK-175				Decreased concentration indicates sulfate utilization by microbes
PLFA (SIP)	^{13}C-enriched content in PLFA	Microbial Insights				Incorporation of ^{13}C in PLFA demonstrates bacteria have degraded ^{13}C-enriched seed contaminant into bacteria cells
DIC (SIP)	^{13}C-enriched content in DIC	Microbial Insights				Incorporation of ^{13}C in DIC demonstrates bacteria have degraded ^{13}C-enriched seed contaminant into dissolved inorganic carbon
SRB (qPCR)	Increased	Microbial Insights				Increased population indicates SRB response to sulfate amendment
EBAC (qPCR)	Increased	Microbial Insights				Increased population indicates total bacteria response to sulfate amendment
QuantArray-Petro (qPCR)	Increased	Microbial Insights				Increased population indicates benzene biodegradation by microbes
PIANO	BTEX+N component decreasing	Pace Analytical				BTEX+N decrease indicates biodegradation by microbes
LNAPL	LNAPL measurements decreasing or consistently low (<1 ft)	field instrument				LNAPL removal to be emphasized over EBR where significant migration to extraction wells occurs.
Temperature	Stable or slowly changing	field instrument				Rapid temperature changes may lead to instability and population changes
pH	In Range	field instrument	6.5-8	5.5-9		Avoid pH range that would inhibit EBR
Eh	Reduced	field instrument	-220	<0	millivolts	(Correct to hydrogen electrode)Eh should be in expected range for anaerobic SRBs
DO	Depleted	field instrument	<0.5	<1.0	mg/L	Anaerobic activity will be inhibited if significant DO is present

Notes:
Parameters to be evaluated in different areas of the site with objective to establish desired trends in all monitored areas of known contamination
*Values as presented in the modeling in RD/RAWP, Appendix E. Update of the groundwater model using data from the full-scale EBR may result in updated values.
**Preliminary ranges for target sulfate concentrations in the formation. Values are subject to modification based on observation of SRB responses in the field to sulfate. Higher concentration may be present in the immediate vicinity of injection wells.

Potential Adjustments:

Condition	Action
1. Limited sulfate distribution	a. Evaluate hydraulic data compared to model predictions.
	b. Inject additional sulfate
	c. Inject sulfate in alternate wells
	d. Extract and recirculate to improve sulfate distribution
	e. Install additional wells for injection/extraction
2. Slow sulfate depletion	a. Evaluate data for possible causes
	b. Investigate with SIP and other supplemental analysis (e.g., for micronutrients)
	c. Estimate revised degradation rates in the model and evaluate redistribution options
3. Limited VOC reduction	a. Review microbial data, perform additional tests if necessary
	b. Additional sulfate injections (if SRB populations confirmed)
	c. Assess back diffusion and LNAPL dissolution as potential causes

Decision Objective: Other non-EBR performance criteria that may require action during active EBR

Time Frame: Any time during active EBR

Criteria:

Parameter	Desired Trend	Method	Discussion
LNAPL Accumulation	LNAPL accumulation remains low	field instrument	LNAPL removal is generally more efficient than EBR. LNAPL not removed can increase EBR timeframe.
VOC migration	VOCs don't migrate to perimeter wells	8260B	VOC migration would expand area requiring treatment
Sulfate migration	Sulfate doesn't significantly migrate outside of COC-areas	field kit/9056A	Sulfate moving outside of COC-impacted areas will not benefit EBR and can cause exceedance of the secondary MCL
Arsenic Concentrations	Arsenic concentrations do not exceed MCL	6010C	Arsenic in injection solution or naturally occurring arsenic liberated by reduced conditions might exceed MCLs
Biofouling	Biofouling does not hinder injections or sulfate distribution	field instrument	Significant changes in water levels or sustainable flow rates in the monitoring/injection/extraction wells with time may indicate biofouling (except what is attributable to the regional rise)

Notes:
Parameters to be evaluated on an individual monitoring well basis for achievement of maximum transition criteria concentrations and on an overall average for average transition criteria.

Potential Contingencies:

Condition	Action
1. LNAPL accumulates >5' in a site well	a. Remove LNAPL from well
2. VOCs migrate to perimeter wells	a. Evaluate if sulfate migration with EBR may eventually address location. If yes, monitor
	b. Evaluate and implement extraction to prevent further migration
3. Sulfate migrates outside COC-areas	a. Depending on location and sulfate concentration, extract and reinject upgradient
4. Arsenic exceeds MCL	a. Adjust injections (if arsenic measured in injection solution)
	b. Evaluate and implement extraction to prevent migration outside the active EBR area
5. Biofouling in injection well	a. Pressurized injections
	b. Well redevelopment
6. Biofouling in formation	a. Develop alternate sulfate injection/delivery for area of fouling

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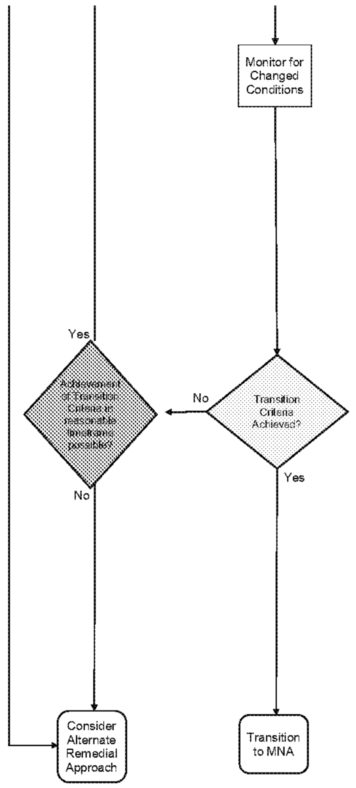
Mesa, Arizona



Decision Objective: Transition Criteria Achieved?
Time Frame: 18-36 months post initial injection

Criteria:

Parameter	Desired Trend	Method	Target Numerical Conditions: Average	Maximum	Units	Discussion
Benzene in CZ	Post EBR model targets met	8260B	21*	27*	µg/L	Average and maximum concentrations consistent with these model values would indicate that MNA could complete remediation in about 13 years.
Benzene in UWBZ	Post EBR model targets met	8260B	210*	1400*	µg/L	Average and maximum concentrations consistent with these model values would indicate that MNA could complete remediation in about 13 years.
Benzene in LSZ	Post EBR model targets met	8260B	31*	270*	µg/L	Average and maximum concentrations consistent with these model values would indicate that MNA could complete remediation in about 13 years.
Sulfate	Sulfate distributed to support ongoing MNA	9056A	2,000-10,000**	30000**	mg/L	Sulfate concentrations in targeted range
LNAPL	No measureable LNAPL in wells	field instrument				LNAPL removal to be emphasized over EBR where significant migration to extraction wells occurs.

Notes:
Parameters to be evaluated for each zone (CZ, UWBZ, and LSZ).
*Values as presented in the modeling in RD/RAWP, Appendix E. Update of the groundwater model using data from the full-scale EBR may result in updated values.
**Preliminary ranges for target sulfate concentrations in the formation. Values are subject to modification based on observation of SRB responses in the field to sulfate. Higher concentration may be present in the immediate vicinity of injection wells.

Potential Adjustments:	Condition	Action
	None - Move to next decision step	Not applicable

Decision Objective: Degradation Trends Support Transition Criteria Can be Achieved in a Reasonable Timeframe or Can be further Optimized
Time Frame: 18-36 months post initial injection

Criteria:

Parameter	Desired Trend	Method	Discussion
CZ Benzene Rate of Change	Benzene half-life supports transition criteria achievement	8260B	Half-life calculations using EBR data support achievement of transition criteria within a ~36 month timeframe.
UWBZ Benzene Rate of Change	Benzene half-life supports transition criteria achievement	8260B	Half-life calculations using EBR data support achievement of transition criteria within a ~36 month timeframe.
LSZ Benzene Rate of Change	Benzene half-life supports transition criteria achievement	8260B	Half-life calculations using EBR data support achievement of transition criteria within a ~36 month timeframe.

Notes:
Parameters to be evaluated on an individual monitoring well basis for achievement of maximum transition criteria concentrations and on an overall average for average transition criteria.

	Condition	Action
Potential Contingencies:	1. Transition criteria achievement not predicted within 36 months post initial injection	a. Implement further optimizations if possible. b. Evaluate among BCT if predicted timeframe is sufficiently close to 36 months to continue with current remedy. If yes, continue active EBR. c. Evaluate alternative approaches (e.g. pump and treat, chemical oxidation, continued active EBR with longer timeframe).

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ATTACHEMENT 6 UPDATED TABLE 5-1 EBR MONITORING, SAMPLING, AND ANALYSIS METHODS AND FREQUENCIES

5.0 EBR SAMPLING AND ANALYSIS

EBR baseline and performance monitoring will be conducted to provide data for evaluation of EBR progress as detailed in this section and Appendix I. Baseline sampling was completed between May and July 2016 for soil and groundwater associated with well installation. In addition, select wells have been sampled during routine perimeter groundwater monitoring events. Given the update to the injection and extraction plan in this addendum and the time since the original baseline sampling, a re-baseline groundwater sampling event is included. After extraction and injections begin, monitoring of EBR operations will include a combination of process monitoring (e.g., pressures, flow rates) and analytical monitoring for TEA distribution, microbial activity, and dissolved concentrations of site COCs to evaluate the progression of EBR. This section discusses the performance monitoring specific to the EBR implementation. Table 5-1 summarizes the monitoring, sampling, and analysis methods and frequencies. Sampling programs are further discussed in the following subsections. Additional detail for EBR sampling and analysis is included in the QAPP/SAP for EBR implementation (included as Appendix I).

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
Baseline (Completed in Spring/Summer 2016)					
Liquid	• Select SIWs and MPE wells (as listed in Table 4-2 of the Draft Final Addendum #2[Amec Foster Wheeler, 2016a]). • All newly installed injection and extraction wells (as listed in Table 4-1 of the Draft Final Addendum #2[Amec Foster Wheeler, 2016a])	• VOCs (8260B) • TPH (8015D, DRO/GRO) • ICP Metals (6010B) • Nitrate and Sulfate (9056A) • Alkalinity (SM 2320B) • Sulfate field screening	• Single event near the end of post-steam extraction activities (existing wells) • At least one week after well development (new wells)	• Performance (Baseline) • Operational Strategy Assessment (adjustments to TEA injection/ extraction strategy)	Yes
Soil	• All drilled locations (drilled using sonic) as listed in the Draft Final Addendum #2[Amec Foster Wheeler, 2016a]	Continuous logging PID readings	• Approximate 10-foot vertical core intervals or where changes are noted.	• Operational Strategy Assessment (injection/ extraction strategy)	No
		• LNAPL Dye Test Kits	• At core intervals of suspected LNAPL based on odor, staining, or PID readings	• Operational Strategy Assessment (injection/	No

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Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
				extraction strategy)	
		• VOCs (EPA 8260B) • TPH (8015D, DRO/GRO)	• 1 per 10 ft interval where dye test kit is positive	• Operational Strategy Assessment (confirmation of qualitative monitoring/ analysis)	Yes
Re-Baseline					
Liquid	Select injection wells:[1] • ST012-SVE04D • ST012-CZ11 • STO12-CZ12 • ST012-CZ16 • ST012-UWBZ10 • ST012-UWBZ16 • ST012-UWBZ23 • ST012-UWBZ33 • ST012-UWBZ34 • ST012-UWBZ36 • ST012-LSZ08 • ST012-LSZ17 • ST012-LSZ43 • ST012-LSZ45 • ST012-LSZ46 • ST012-LSZ49 Select extraction wells:[1] • ST012-CZ07 • ST012-CZ18 • ST012-CZ19 • ST012-CZ21 • ST012-UWBZ22 • ST012-UWBZ26 • ST012-UWBZ27 • ST012-UWBZ30 • ST012-LSZ09 • ST012-LSZ11 • ST012-LSZ12 • ST012-LSZ23 • ST012-LSZ29 • ST012-LSZ37 • ST012-LSZ38	• VOCs (8260B) • TPH (8015D, DRO/GRO)[4] • ICP Metals (6010B) • Nitrate and Sulfate (9056A) • Total and ferrous iron field screening (test 3 high iron and 3 low iron locations)	• Single event prior to beginning EBR extraction and injections	• Performance (Baseline)	Yes

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
	• ST012-LSZ39 • ST012-UWBZ28/LSZ51 Select monitoring wells:[1] • ST012-CZ02 • ST012-CZ06 • ST012-CZ08 • ST012-CZ09 • ST012-CZ14 • ST012-CZ15 • ST012-CZ20 • ST012-CZ23 • ST012-CZ24 • ST012-CZ25 • ST012-UWBZ05 • ST012-UWBZ09 • ST012-UWBZ11 • ST012-UWBZ14 • ST012-UWBZ18 • ST012-UWBZ24 • ST012-UWBZ31 • ST012-UWBZ38 • ST012-UWBZ39 • ST012-LSZ02 • ST012-LSZ03 • ST012-LSZ06 • ST012-LSZ10 • ST012-LSZ15 • ST012-LSZ19 • ST012-LSZ22 • ST012-LSZ25 • ST012-LSZ42 • ST012-LSZ52 • ST012-LSZ53 • ST012-LSZ54 • ST012-LSZ55 • ST012-LSZ56 • ST012-LSZ57 • ST012-LSZ59				
Liquid - LNAPL	Select wells with LNAPL[2]: • ST012-CZ01 • ST012-UWBZ17 • ST012-UWBZ33	• PIANO	• Single event prior to beginning EBR injections. May be collected during extraction prior to	• Performance (baseline)	Yes

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
	• ST012-LSZ30 • ST012-LSZ43 • ST012-LSZ50 • ST012-W11 • ST012-W37		injections if water table drawdown promotes additional LNAPL accumulations.		
Liquid/ Bio-trap®	Select monitoring wells: • ST012-CZ02 • ST012-CZ20 • ST012-UWBZ24 • ST012-UWBZ31 • ST012-LSZ10 • ST012-LSZ42	• SRB (qPCR) • EBAC (qPCR) • QuantArray-Petro (qPCR)	• Single event prior to beginning EBR extraction and injections	• Performance (Baseline)	Yes
Injection Material, Injection Solution, and Injection Well Sampling					
Solid	• Sodium sulfate composite	• ICP Metals (6010B) • Sulfate (9056A)	• 1 per delivery lot	• Operational Strategy (verification of TEA content and check impurities)	Yes
Liquid	• TEA Injection fluid	• Sulfate field screening	• Daily	• Operational Strategy (verification of TEA concentration)	No
	• TEA Injection fluid	• ICP Metals (6010B) • Sulfate (9056A)	• Weekly	• Operational Strategy (verification of TEA concentration)	Yes
Liquid	• Injection locations (31) (as listed in Table 4-1)[1]	• VOCs (8260B) • ICP Metals (6010B) • Sulfate and Nitrate (9056A)	• Quarterly	• Performance (dissolved VOCs reduction, TEA solution distribution, dissolved metals monitoring)	Yes
Extraction Well Sampling					
Liquid	• Extraction locations (20) (as listed in Table 4-1 except sampling frequency is	• VOCs (8260B)	• Quarterly	• Performance (dissolved COCs reduction) • Operational Strategy Assessment	Yes

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
	higher for wells in next row)[1,2]			(bioactivity and TEA distribution)	
		• TPH (8015D, DRO/GRO) • ICP Metals (6010B)	• Semiannual	• Performance • Compliance (trace metals monitoring)	Yes
		• Sulfate Field Screening • Sulfate (9056A)	• Biweekly during the first month (sulfate only), then transition to monthly thereafter with confirmatory off-site laboratory analysis (9056A) for every 10% of field screening samples • Continue monthly after extraction turned off	• Operational Strategy Assessment (TEA distribution)	Yes
Liquid	Select extraction wells:[1] • ST012-CZ18 • ST012-CZ19 • ST012-CZ21 • ST012-UWBZ26 • ST012-UWBZ28/LSZ51 • ST012-LSZ28 • ST012-LSZ38	• Sulfate Field Screening • Sulfate (9056A)	• Weekly during the first two months, then transition to monthly thereafter with confirmatory off-site laboratory analysis for every 10% of field screening samples • Continue monthly after extraction turned off	• Operational Strategy Assessment (TEA distribution)	Yes
Groundwater Monitoring Well Sampling					
Liquid	Groundwater/ Perimeter monitoring wells[1]: • ST012-C02 • ST012-U02 • ST012-W12 • ST012-U37 • ST012-RB-3A • ST012-W24 • ST012-U38 • ST012-W38 • ST012-U11	• VOCs (8260B) • ICP Metals (6010B) • Sulfate (9056A) • TPH (8015D) • Phosphorous as orthophosphate (300.0) • Methane (RSK-175)	• Quarterly	• Performance (dissolved COCs reduction) • Operational Strategy Assessment (TEA distribution)	Yes

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
	• ST012-U12 • ST012-CZ02 • ST012-CZ06 • ST012-CZ08 • ST012-CZ09 • ST012-CZ14 • ST012-CZ15 • ST012-CZ20 • ST012-CZ23 • ST012-CZ24 • ST012-CZ25 • ST012-UWBZ05 • ST012-UWBZ09 • ST012-UWBZ11 • ST012-UWBZ14 • ST012-UWBZ18 • ST012-UWBZ24 • ST012-UWBZ31 • ST012-UWBZ38 • ST012-UWBZ39 • ST012-LSZ02 • ST012-LSZ03 • ST012-LSZ06 • ST012-LSZ10 • ST012-LSZ15 • ST012-LSZ19 • ST012-LSZ22 • ST012-LSZ25 • ST012-LSZ42 • ST012-LSZ52 • ST012-LSZ53 • ST012-LSZ54 • ST012-LSZ55 • ST012-LSZ56 • ST012-LSZ57 • ST012-LSZ59				
Liquid - LNAPL	Select wells with LNAPL[2]: • ST012-CZ01 • ST012-UWBZ17 • ST012-UWBZ33 • ST012-LSZ30 • ST012-LSZ43 • ST012-LSZ50 • ST012-W11	• PIANO	• Annually if samples of LNAPL can be collected	• Performance (change in LNAPL composition)	Yes

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
	• ST012-W37				
Liquid/ Bio-trap®	Select monitoring wells: • ST012-CZ02 • ST012-CZ20 • ST012-UWBZ24 • ST012-UWBZ31 • ST012-LSZ10 • ST012-LSZ42	• SIP (^{13}C in PLFA and DIC) • SRB (qPCR) • EBAC (qPCR) • QuantArray-Petro (qPCR)	• It is estimated that analysis is likely to occur between six and twelve months following the initiation of sulfate injections based on field conditions (including sulfate travel time and groundwater temperatures). Once initial microbial analysis is conducted, future sampling will be conducted based on evidence of SRB and biodegradation.	• Performance (SRB population, evidence of biodegradation) • Operation Strategy Assessment (TEA distribution)	Yes
Liquid	• Annual Groundwater Monitoring Locations (see AMEC, 2013 with modified locations per Table 5-3 of the RD/RAWP, except locations that exceed temperature limits of low-flow sampling equipment will not be sampled)[1]	• See AMEC, 2013	• Annual	• Compliance (RODA 2)	No
Process Water Sampling					
Liquid	• Treatment System Influent	• VOCs (8260B) • TPH (8015D, DRO/GRO)	• Monthly	• Performance (mass removal)	Yes

Table 5-1 EBR Monitoring, Sampling, and Analysis Methods and Frequencies

Media	Locations	Monitoring/ Analysis	Frequency	Sample Purpose	Additional Information in QAPP/SAP
Liquid	• GAC Influent • GAC Midfluent	• VOCs (8260B)	• Weekly for influent and midfluent until influent concentrations stabilize, then monthly	• Performance (mass removal by GAC) • Operation (breakthrough at Midfluent) • Compliance (effluent discharge permit)	Yes
	• GAC Effluent	• VOCs (8260B)	• Monthly	• Operation (breakthrough at Midfluent) • Compliance (effluent discharge permit)	Yes
		• TPH (8015D)[3] • Oil and Grease (E1664)[3] • SVOCs (8270C)[1] • Pesticides/PCBs (8081A/8082)[1] • HRGC/HRMS (modified 8081A)	• Quarterly	• Compliance (effluent discharge permit)	Yes
	• Effluent Discharge	• Liquid Discharge Flow Rate	• Daily flow meter readings[1]	• Compliance (effluent discharge permit)	No

Notes:
ASTM – American Society for Testing Materials
DIC – dissolved inorganic carbon
DO – dissolved oxygen
DRO – diesel range organics
EBAC – total eubacteria
FID – flame ionization detector
GAC – granular activated carbon
GC – gas chromatograph
GRO – gasoline range organics
HRGC/HRMS – high resolution gas chromatography/high resolution mass spectrometry
LNAPL – light non-aqueous phase liquid
MPE – multi-phase extraction
ORP – oxidation-reduction potential
PCBs – polychlorinated biphenyls
PIANO - paraffins, isoparaffins, aromatics, naphthalenes, and olefins
PID – photoionization detector
PLC – programmable logic controller